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Lee et al.

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(54) **FINFETS WITH STRAINED WELL REGIONS**
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None
See application file for complete search history.

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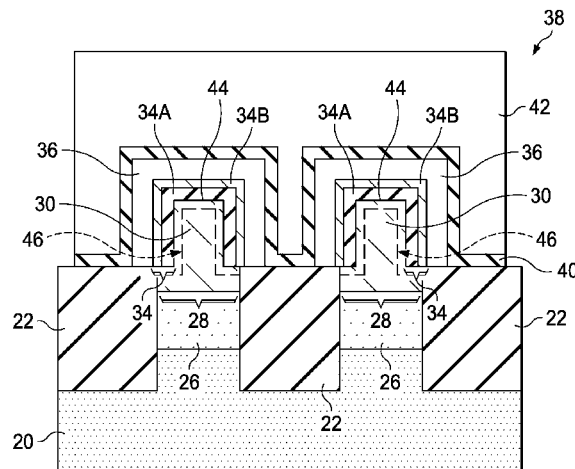
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(57) **ABSTRACT**

A device includes a substrate and insulation regions over a portion of the substrate. A first semiconductor region is between the insulation regions and having a first conduction band. A second semiconductor region is over and adjoining the first semiconductor region, wherein the second semiconductor region includes an upper portion higher than top surfaces of the insulation regions to form a semiconductor fin. The second semiconductor region also includes a wide portion and a narrow portion over the wide portion, wherein the narrow portion is narrower than the wide portion. The semiconductor fin has a tensile strain and has a second conduction band lower than the first conduction band. A third semiconductor region is over and adjoining a top surface and sidewalls of the semiconductor fin, wherein the third semiconductor region has a third conduction band higher than the second conduction band.

20 Claims, 7 Drawing Sheets



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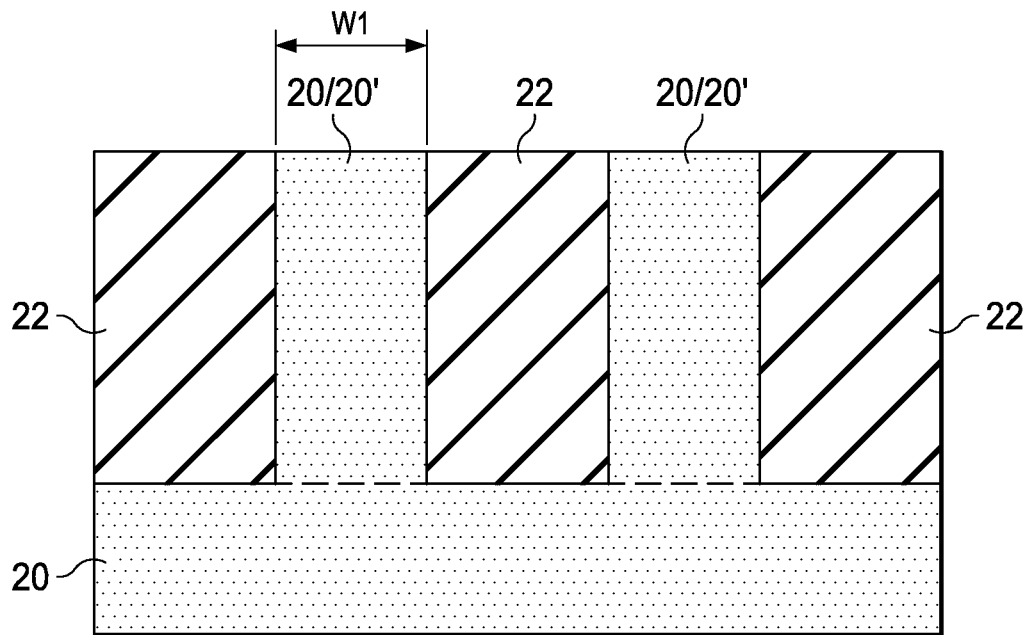


FIG. 1

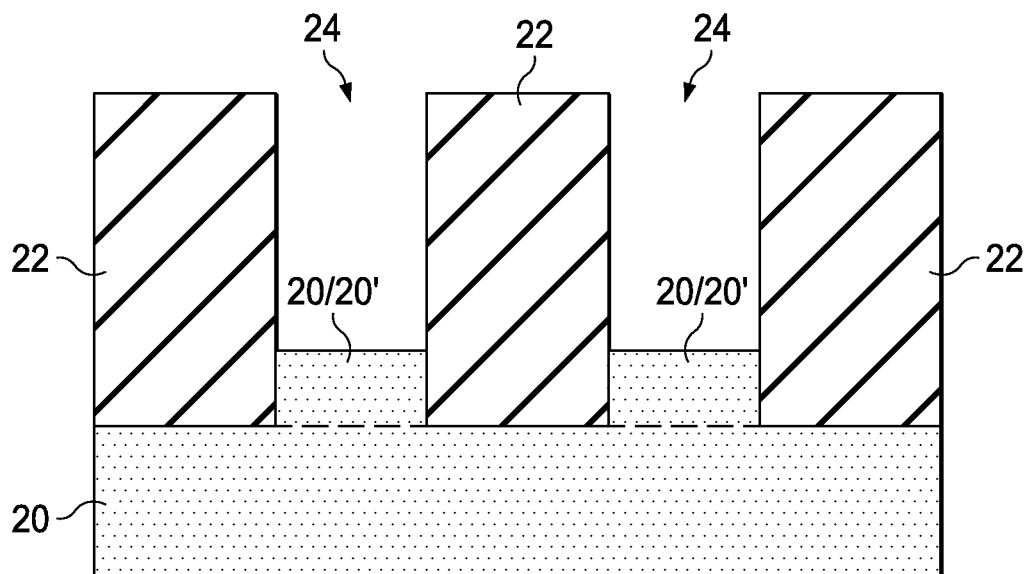


FIG. 2

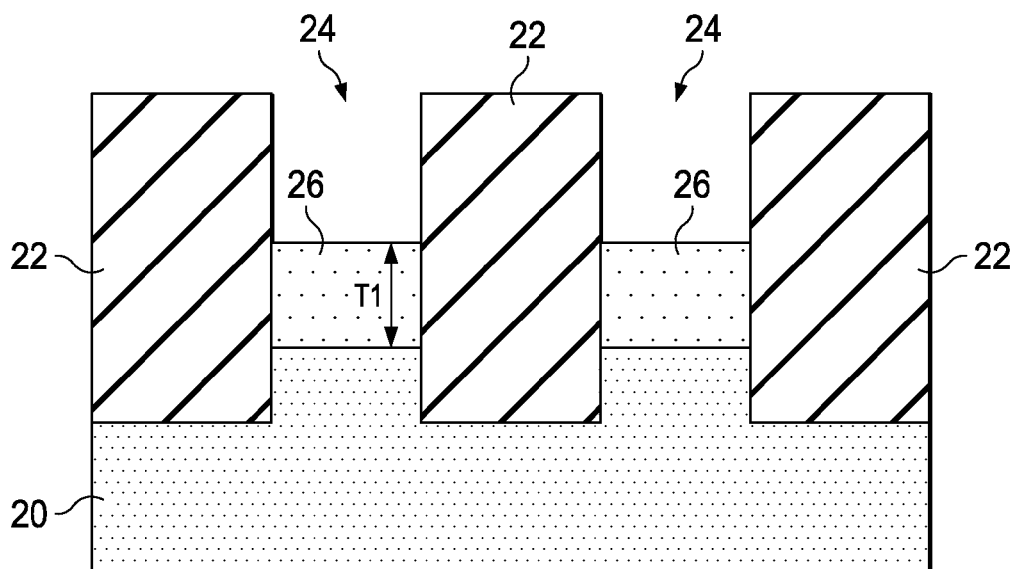


FIG. 3

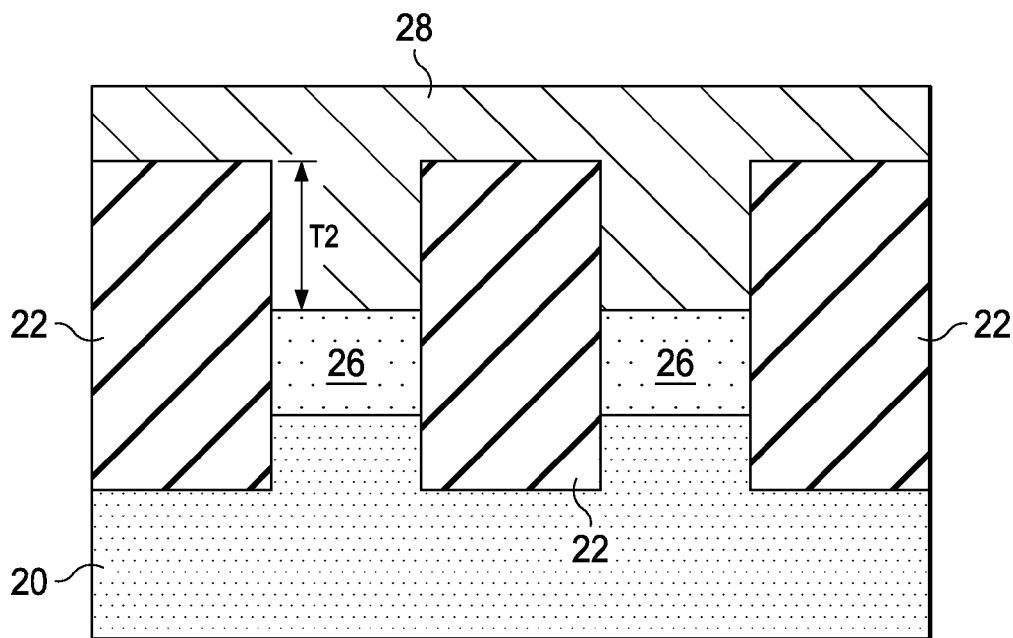


FIG. 4

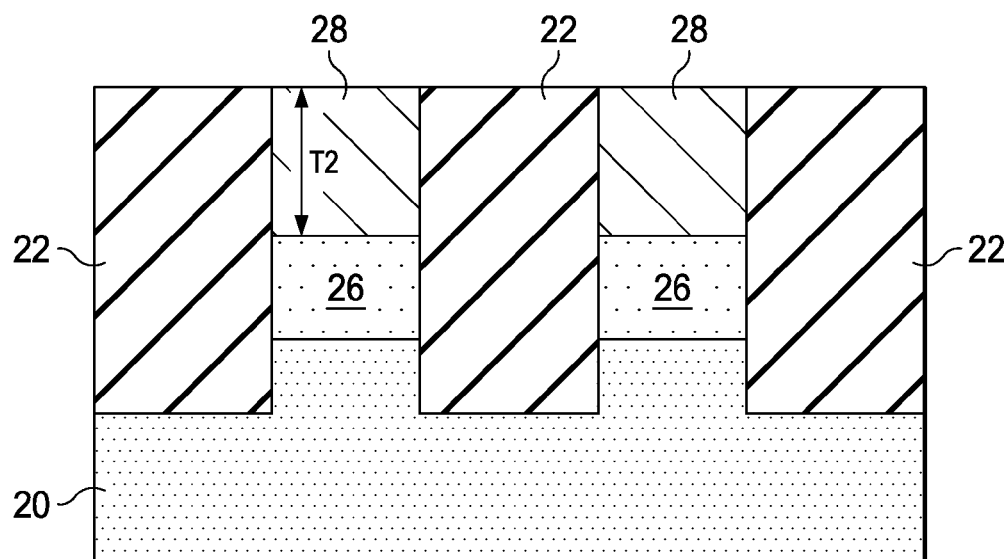


FIG. 5

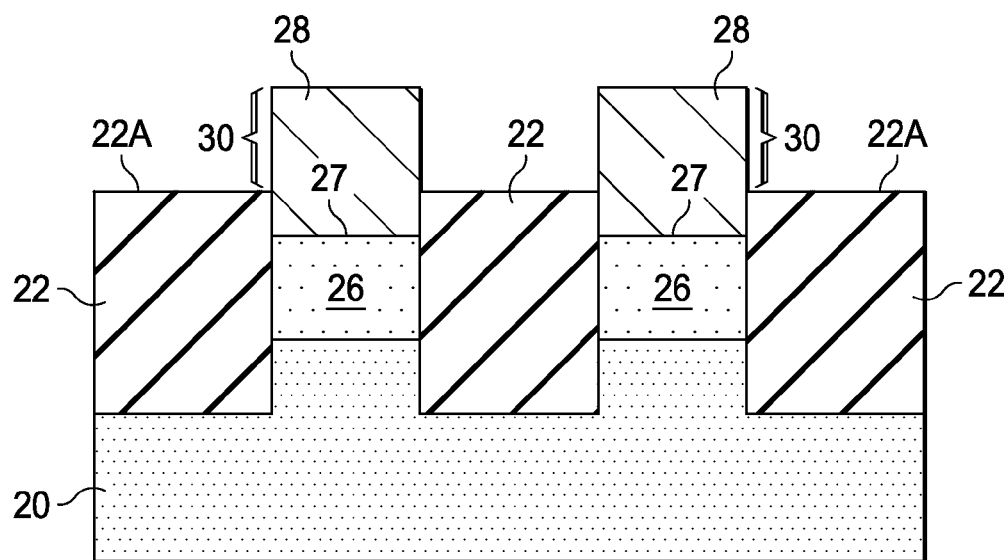


FIG. 6

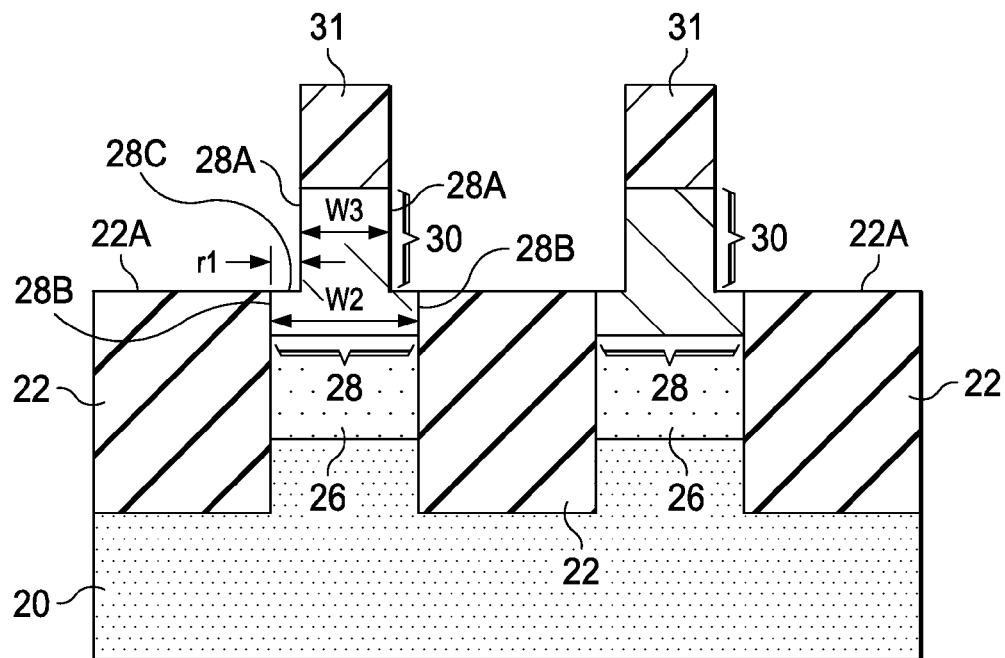


FIG. 7

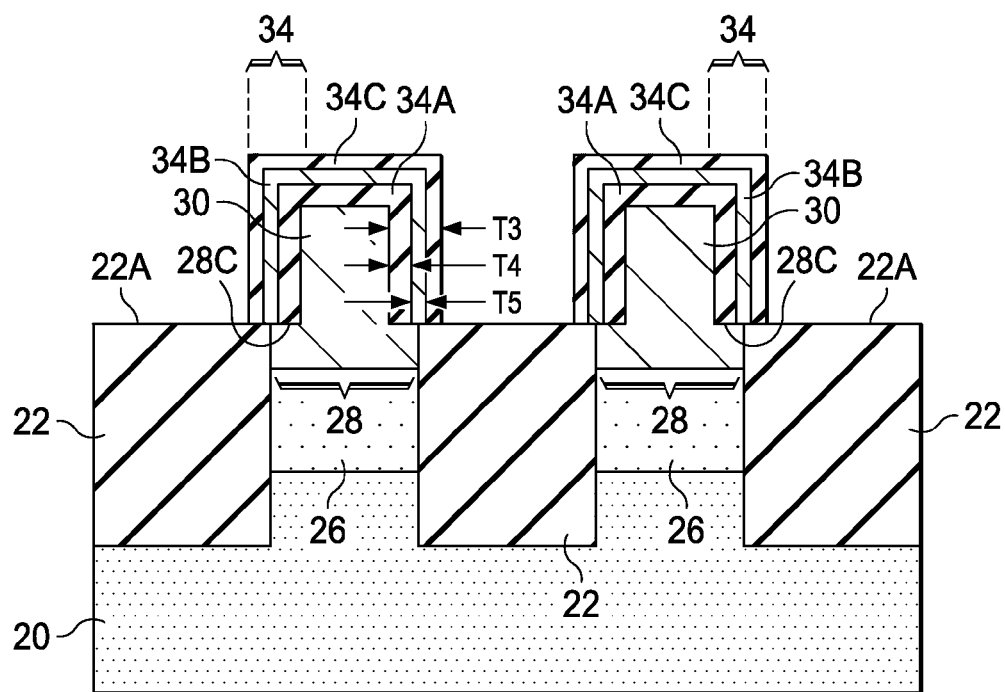


FIG. 8

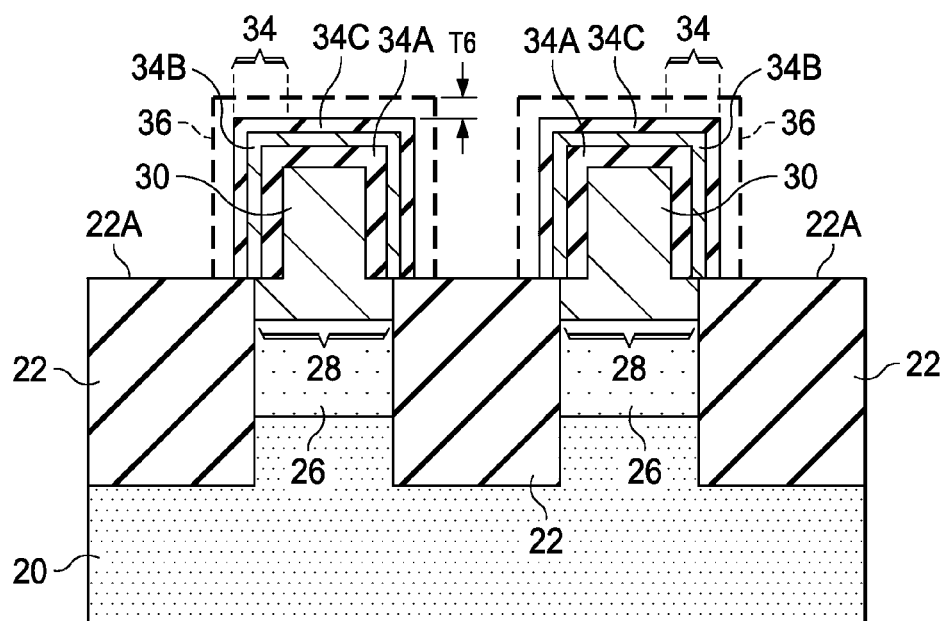


FIG. 9

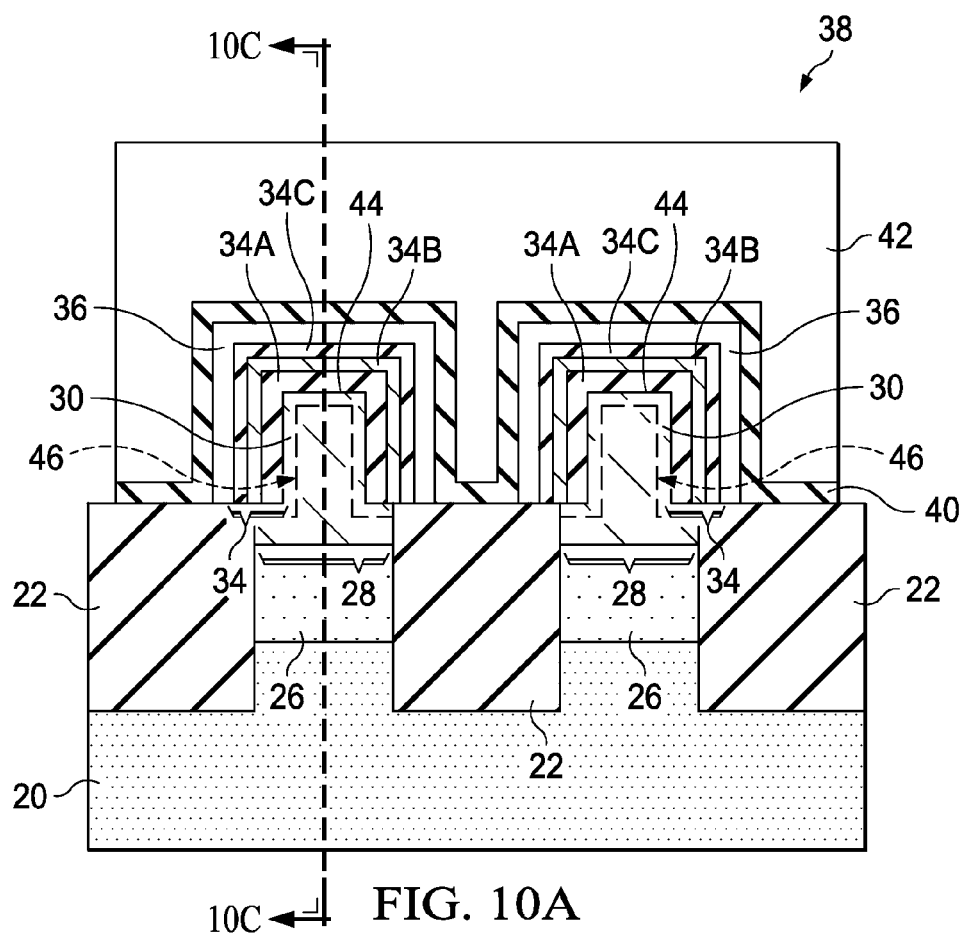


FIG. 10A

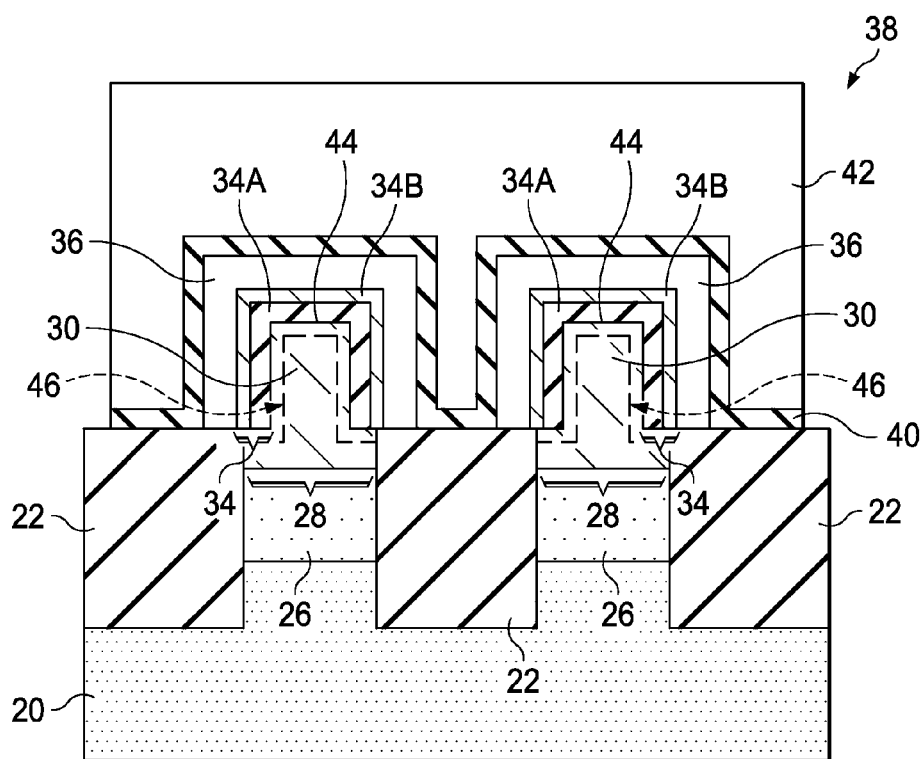


FIG. 10B

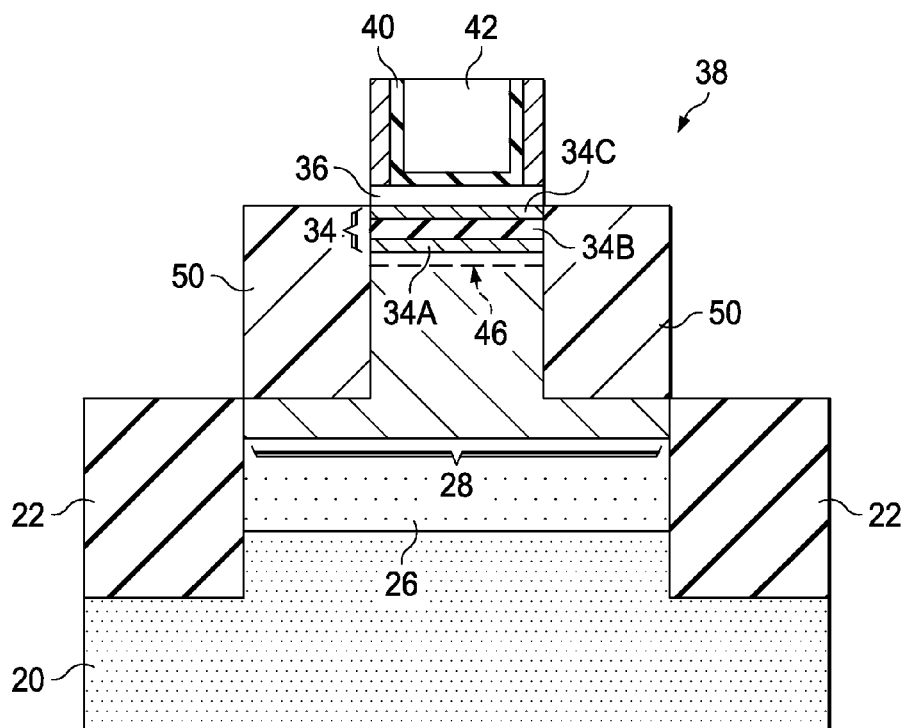


FIG. 10C

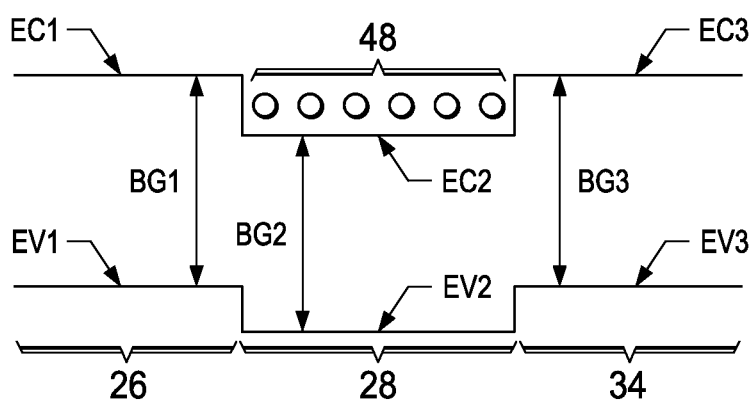


FIG. 11

FINFETS WITH STRAINED WELL REGIONS

CROSS-REFERENCE TO RELATED APPLICATION

This application relates the following commonly-assigned U.S. patent application: application Ser. No. 13/779,015, filed Feb. 27, 2013, and entitled "FinFETs with Strained Well Regions", which application is hereby incorporated herein by reference.

BACKGROUND

The speed of metal-oxide-semiconductor (MOS) transistors are closely related to the drive currents of the MOS transistors, which are further closely related to the mobility of charges in the channels of the MOS transistors. For example, NMOS transistors have high drive currents when the electron mobility in their channel regions is high, while PMOS transistors have high drive currents when the hole mobility in their channel regions is high. Germanium, silicon germanium, and compound semiconductor materials (referred to as III-V compound semiconductors hereinafter) comprising group III and group V elements are thus good candidates for forming their high electron mobility and/or hole mobility.

Germanium, silicon germanium, and III-V compound semiconductor regions are also promising materials for forming the channel regions of Fin Field-Effect transistors (FinFETs). Methods and structures for further improving the drive currents on the FinFETs are currently being studied.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the embodiments, and the advantages thereof, reference is now made to the following descriptions taken in conjunction with the accompanying drawings, in which:

FIGS. 1 through 10C are cross-sectional views of intermediate stages in the manufacturing of a semiconductor fin and a Fin Field-Effect Transistor (FinFET) in accordance with some exemplary embodiments; and

FIG. 11 illustrates a band diagram of a plurality of semiconductor regions in the FinFET.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

The making and using of the embodiments of the disclosure are discussed in detail below. It should be appreciated, however, that the embodiments provide many applicable concepts that can be embodied in a wide variety of specific contexts. The specific embodiments discussed are illustrative, and do not limit the scope of the disclosure.

Fin Field-Effect Transistors (FinFETs) and methods of forming the same are provided in accordance with various exemplary embodiments. The intermediate stages of forming the FinFETs in accordance with some embodiments are illustrated. The variations of the embodiments are discussed. Throughout the various views and illustrative embodiments, like reference numbers are used to designate like elements.

Referring to FIG. 1, substrate 20 is provided. Substrate 20 may be a semiconductor substrate such as a crystalline silicon substrate. Substrate 20 may also include silicon, germanium, carbon, or the like. Insulation regions such as Shallow Trench Isolation (STI) regions 22 are formed in substrate 20. STI regions 22 may be formed by recessing semiconductor substrate 20 to form trenches, and then filling the trenches with

dielectric materials such as silicon oxide. A Chemical Mechanical Polish (CMP) is then performed to remove excess portions of the dielectric materials, and the remaining portions are STI regions 22. The top surfaces of STI regions 22 are thus level with the top surface of substrate 20.

STI regions 22 include neighboring regions having their sidewalls facing each other. Portions 20' of substrate 20 extend between the neighboring STI regions. Width W1 of substrate portions 20' may be between about 10 nm and about 200 nm. It is appreciated that the dimensions recited throughout the description are merely examples, and may be changed to different values. The neighboring STI regions may be separate regions, or may be portions of a continuous region, which may form a STI ring in some embodiments.

Referring to FIG. 2, substrate portions 20' are recessed, forming recesses 24 between neighboring STI regions 22. In some embodiments, the bottoms of recesses 24 are higher than the bottom surfaces of STI regions 22. In alternative embodiments, the bottoms of recesses 24 are substantially level with or lower than the bottoms of STI regions 22.

Referring to FIG. 3, semiconductor regions 26 are grown in recesses 24 through epitaxy. The top surfaces of semiconductor regions are lower than the top surfaces of STI regions 22. Semiconductor regions 26 may have a first lattice constant greater than the lattice constant of substrate 20. In some embodiments, semiconductor regions 26 comprises silicon germanium, which is expressed as $\text{Si}_{1-X}\text{Ge}_X$, wherein value X is the atomic percentage of germanium in semiconductor regions 26, which atomic percentage may be between about 0.2 (20 percent) and 1 (100 percent) in exemplary embodiments. Semiconductor regions 26 are a relaxed semiconductor region, which means that at least the top portions of semiconductor regions are relaxed with substantially no stress. This may be achieved by, for example, making thickness T1 great enough, since the stresses in upper portions of semiconductor regions 26 are increasingly smaller than the lower portions. In some exemplary embodiments, thickness T1 is greater than about 30 nm, and may be between about 30 nm and about 150 nm. In some exemplary embodiments, the conduction band of semiconductor regions 26 is lower than the conduction band of bulk silicon by between about 0.036 eV and about 0.144 eV, wherein the conduction band of silicon is about 1.1 eV. FIG. 11 schematically illustrates band-gap BG1, conduction band Ec1, and valence band Ev1 of semiconductor regions 26.

Next, referring to FIG. 4, semiconductor regions 28 are grown in recesses 24 through epitaxy, wherein semiconductor regions 28 are grown over and contacting semiconductor regions 26. Semiconductor regions 28 have a tensile strain, and may be un-doped with n-type and p-type impurities. In some embodiments, the tensile strain is generated by making the lattice constant of semiconductor regions 28 smaller than the lattice constant of semiconductor regions 26. In some embodiments, the tensile strain is higher than about 1.36 MPa, and may be higher than about 6.8 GPa. Semiconductor regions 28 include portions in recesses 24 (FIG. 3), which portions have thickness T2. Thickness T2 is small enough, so that after the subsequent Chemical Mechanical Polish (CMP) in FIG. 5, semiconductor regions 28 are not relaxed and have the tensile strain. In some exemplary embodiments, thickness T2 is smaller than about 150 nm, and may be between about 30 nm and about 150 nm.

FIG. 11 schematically illustrates bandgap BG2, conduction band Ec2, and valence band Ev2 of semiconductor regions 28. Conduction band Ec2 is lower than the conduction band Ec1 of semiconductor regions 26, with the difference (Ec1-Ec2) being greater than about 0.036 eV, for example. In

some embodiments, semiconductor regions **28** comprise $\text{Si}_{1-Y}\text{Ge}_Y$, wherein value Y is the atomic percentage of germanium in semiconductor regions **28**. Value Y may be smaller than about 0.3 (30 percent), and may be between 0 and about 0.3. Value Y may also be equal to 0, which means that semiconductor regions **28** are silicon regions free from germanium. Furthermore, value Y is smaller than value X of semiconductor regions **26**, with the difference (X-Y) being greater than about 0.1, greater than about 0.3, or greater than about 0.5, for example. A greater difference (X-Y) may advantageously result in a greater tensile strain in semiconductor regions **28**, and a greater conduction band difference (Ec1-Ec2).

Semiconductor regions **28** may be grown to a level higher than the top surfaces of STI regions **22**. A CMP is then performed to level the top surface of STI regions **22** and semiconductor regions **28**. The resulting structure is shown in FIG. 5. In alternative embodiments, the growth of semiconductor regions **28** stops at a time when the top surface of semiconductor regions **28** is level with or lower than the top surfaces of STI regions **22**. In these embodiments, the CMP may be performed, or may be skipped.

Referring to FIG. 6, STI regions **22** are recessed, for example, through an etching step. The top surfaces **22A** of the remaining STI regions **22** are higher than the interfaces **27** between semiconductor regions **26** and semiconductor regions **28**. The portions of semiconductor regions **28** that are higher than top surfaces **22A** are referred to as semiconductor fins **30** hereinafter.

FIG. 7 illustrates the thinning of semiconductor regions **28**. In some embodiments, the thinning is performed by applying and patterning photo resist **31**, and then using photo resist **31** as a mask to etch semiconductor fins **30**. As a result of the thinning, semiconductor regions **28** have lower portions and upper portions narrower than the lower portions. The lower portions have width W2, and the upper portions have width W3, wherein both widths W2 and W3 are measured close to the transition region transiting from the narrow portions to the wide portions. In some embodiments, width W2 is between about 8 nm and about 200 nm, and width W3 is between about 6 nm and about 200 nm. The difference (W2-W3) may be greater than about 2 nm, or greater than about 5 nm, for example. In some exemplary embodiments, an entirety of semiconductor fins **30** is thinned. In alternative embodiments, an upper portion of each of semiconductor fins **30** is thinned, and the lower portion of each of semiconductor fins **30** remains not thinned.

Due to the thinning, the narrow portions of semiconductor regions **28** have sidewalls **28A**, and the wide portions of semiconductor regions **28** have sidewalls **28B**, which are vertically misaligned to the respective overlying sidewalls **28A**. Furthermore, sidewalls **28B** are not continuously transitioned to the respective overlying sidewalls **28A**. Rather, top surfaces **28C** of the wide portions connect sidewalls **28B** to the respective overlying sidewalls **28A**. Top surface **28C** may be substantially flat in some embodiments. Sidewalls **28B** and the respective overlying sidewalls **28A** may be misaligned by misalignment r1, which may be greater than about 1 nm, or greater than about 5 nm. Top surfaces **28C** may be level with the top surface **22A** of STI regions **22**. Alternatively, although not shown, top surfaces **28C** are higher than the top surface **22A** of STI regions **22**.

FIG. 8 illustrates the formation of semiconductor regions **34**, which are epitaxially grown on the exposed top surfaces and sidewalls of semiconductor fins **30**. Semiconductor regions **34** are substantially conformal layers, with the portions on the top surfaces of semiconductor fins **30** having substantially the same thickness T3 as the portions on the

sidewalls of semiconductor fins **30**. In some embodiments, thickness T3 is between about 5 nm and about 150 nm. Semiconductor regions **34** are in contact with the top surfaces and the sidewalls of the narrow portions of semiconductor regions **28**, and in contact with the top surfaces **28C** of the wide portions of semiconductor regions **28**. In the embodiments that top surfaces **28C** are higher than top surfaces **22A** of STI regions **22**, semiconductor regions **34** are also grown on the sidewalls of the wide portions of semiconductor regions **28**.

Bandgap BG3, conduction band Ec3, and valence band Ev3 of semiconductor regions **34** are schematically illustrated in FIG. 11. Conduction band Ec3 is higher than conduction band Ec2 of semiconductor regions **28**, with the difference (Ec3-Ec2) being greater than about 0.036 eV, for example. In some embodiments, semiconductor regions **28** comprise $\text{Si}_{1-Z}\text{Ge}_Z$, wherein value Z is the atomic percentage of silicon in semiconductor regions **34**. Value Z may be greater than about 0.3, and may be between about 0.3 and 1. Value Z may also be equal to 1, which means that semiconductor regions **34** are pure germanium regions free from silicon. Furthermore, value Z is greater than value Y of semiconductor regions **28**, with the difference (Z-Y) being greater than about 0.1, or greater than about 0.3, for example. A greater difference (Z-Y) may advantageously result in a greater conduction band difference (Ec3-Ec2).

In some embodiments, semiconductor regions **34** include layers **34A** and layers **34B**, which are formed over layers **34A**. Layers **34A** and layers **34B** may have substantially the same atomic percentage of silicon and substantially the same atomic percentage of germanium, although their compositions may also be different from each other. In some exemplary embodiments, layers **34A** are not doped with n-type impurities, and may also be free from p-type impurities. In alternative embodiments, layers **34A** are n-type doped layers with the n-type impurity concentration lower than about $10^{16}/\text{cm}^3$, for example. Thickness T4 of layers **34A** may be greater than 0 nm and smaller than about 50 nm. Layers **34B** are n-type layers, wherein the n-type impurity concentration in layers **34B** may be higher than about $10^{18}/\text{cm}^3$. In these embodiments, the n-type impurity concentration in layers **34A** is lower than the n-type impurity concentration in layers **34B**. Layers **34B** act as the electron-supply layers for supplying electrons to the underlying carrier channels **46** (FIG. 10A through 10C).

The doped n-type impurity may include phosphorous, arsenic, antimony, or combinations thereof. Layers **34A** and layers **34B** may be formed in-situ in a same vacuum chamber, and may be formed using essentially the same process conditions, except that in the formation of layers **34A**, no n-type dopant is added, while the n-type dopant is added in the formation of layers **34B**. Alternatively, in the formation of both layers **34A** and **34B**, n-type dopants are added, and the n-type dopant amount for forming layers **34A** is smaller than that for forming layers **34B**. In some embodiments, thickness T5 of doped layers **34B** is between about 1 nm and about 20 nm.

In some embodiments, semiconductor regions **34** further include layers **34C** over layers **34B**. Layers **34C** may have atomic percentages of silicon and germanium same as either one, or both, of layers **34A** and **34B**. In alternative embodiments, the silicon and germanium atomic percentages in layers **34A**, **34B**, and **34C** are all different from each other. Layers **34C** may also be un-doped with n-type impurities, or doped with n-type impurities that have a lower impurity concentration than the respective underlying layers **34B**. In alter-

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native embodiments, layers 34C are not formed, and the respective structure may be found in FIG. 10B.

FIG. 9 illustrates the formation of silicon caps 36, which may be substantially pure silicon regions with no germanium added. Silicon caps 36 may also be formed through epitaxy, and hence are over the top portions and sidewall portions of semiconductor regions 34. In some embodiments, no n-type and p-type impurities are added into silicon caps 36, although n-type and p-type impurities with low concentrations, for example, lower than about $10^{16}/\text{cm}^3$, may also be added. Thickness T6 of silicon caps 36 may be between about 1 nm and about 20 nm in some embodiments. In alternative embodiments, silicon caps 36 are not formed.

The structure shown in FIG. 9 may be used to form FinFET 38, as shown in FIGS. 10A, 10B, and 10C. Referring to FIG. 10A, gate dielectric 40 and gate electrode 42 are formed. Gate dielectric 40 may be formed of a dielectric material such as silicon oxide, silicon nitride, an oxynitride, multi-layers thereof, and/or combinations thereof. Gate dielectric 40 may also be formed of high-k dielectric materials. The exemplary high-k materials may have k values greater than about 4.0, or greater than about 7.0. Gate electrode 42 may be formed of doped polysilicon, metals, metal nitrides, metal silicides, and the like. The bottom ends of gate dielectric 42 may contact the top surfaces of STI regions 22. After the formation of gate dielectric 40 and gate electrode 42, source and drain regions 50 (FIG. 10C) are formed.

As shown in FIG. 10A, semiconductor regions 28 form interfaces 44 with the adjoin semiconductor regions 34. Carrier channels 46, which are alternatively referred to as Two-Dimensional Electron Gas (2DEG) channels, are formed and located in semiconductor regions 28. 2DEG channels 46 may also be close to interfaces 44. Although semiconductor regions 28 may not be doped with n-type impurities, carrier channels 46 still have a high density of electrons, which are supplied by the respective overlying electron-supply layers 34B.

FIG. 10B illustrates a cross-sectional view of FinFET 38 in accordance with alternative embodiments. These embodiments are essentially the same as the embodiments in FIG. 10A, except that the layer 34C in FIG. 10A is not formed. Accordingly, silicon caps 36 are in physical contact with the respective underlying layers 34B.

FIG. 10C illustrates a cross-sectional view of FinFET 38, wherein the cross-sectional view is obtained from the plane crossing line 10C-10C in FIG. 10A. Source and drain regions 50 are formed on the opposite sides of gate dielectric 40 and gate electrode 42. Source and drain regions 50 are doped with an n-type impurity such as phosphorous, arsenic, antimony, or the like, and hence the respective FinFET 38 is an n-type FinFET. 2DEG channel 46 interconnects the source and drain regions 50.

FIG. 11 schematically illustrates a band diagram of semiconductor regions 26, 28, and 34. As shown in FIG. 11, the conduction band Ec2 of semiconductor region 28 is lower than conduction band Ec1 of semiconductor region 26 and conduction band Ec3 of semiconductor region 34. Accordingly, conduction bands Ec1, Ec2, and Ec3 form a well, with conduction band Ec2 forming the bottom of the well. Electrons 48, which are supplied by electron-supply layers 34B (FIGS. 10A and 10B), are confined in the well to form the 2DEG channels. The formation of the well is attributed to that semiconductor region 28 is tensile strained, and hence conduction band Ec2 is suppressed to a level lower than conduction bands Ec1 and Ec3. As a comparison, if semiconductor region 28 is not tensile strained, the conduction band of semiconductor region 28 will be higher than the conduction bands

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of semiconductor regions 26 and 34, and hence the well region and the 2DEG channel will not be formed. In addition, since semiconductor region 28 may not be doped with impurities, electrons can move freely without collision or with substantially reduced collisions with the impurities.

In the embodiments of the present disclosure, by forming relaxed semiconductor region 26 that has a greater lattice constant than the lattice constant of semiconductor region 28, the overlying semiconductor region 28 may have a tensile strain. The tensile strain results in a conduction band well to be formed in semiconductor region 28. Furthermore, electron-supply layer 34B is formed overlying semiconductor region 28 to supply electrons, which are confined in the well formed in semiconductor region 28 to form the 2DEG channel. Accordingly, the resulting FinFET has a high saturation current.

In addition, in the embodiments of the present disclosure, by thinning semiconductor fins, more spaces are provided for forming semiconductor layers on the sidewalls of semiconductor fins. The required chip area occupied by the respective FinFET is hence reduced. The channel width of the respective FinFET, however, is not adversely reduced since the total width of the 2DEG channel is not reduced compared to the scenario that no thinning is performed.

In accordance with some embodiments, a device includes a substrate and insulation regions over a portion of the substrate. A first semiconductor region is between the insulation regions and having a first conduction band. A second semiconductor region is over and adjoining the first semiconductor region, wherein the second semiconductor region includes an upper portion higher than top surfaces of the insulation regions to form a semiconductor fin. The second semiconductor region also includes a wide portion and a narrow portion over the wide portion, wherein the narrow portion is narrower than the wide portion. The semiconductor fin has a tensile strain and has a second conduction band lower than the first conduction band. A third semiconductor region is over and adjoining a top surface and sidewalls of the semiconductor fin, wherein the third semiconductor region has a third conduction band higher than the second conduction band.

In accordance with other embodiments, a device includes a silicon substrate and STI regions over a portion of the silicon substrate. A first SiGe region is located between and in contact with the STI regions, wherein the first SiGe region has a first germanium atomic percentage. A silicon-containing region is over the first SiGe region. The silicon-containing region has a tensile stress. A second SiGe region contacts a top surface and sidewalls of the silicon-containing region. The silicon-containing region has a wide portion having a first sidewall and a top surface, and a narrow portion over the wide portion and having a second sidewall. The first sidewall and the second sidewall are on a same side of the silicon-containing region. Edges of the wide portion are vertically aligned to respective edges of the first SiGe region. The top surface of the wide portion connects the first sidewall to the second sidewall. The second SiGe region has second germanium atomic percentage. The first and the second germanium atomic percentages are higher than a third germanium atomic percentage of the silicon-containing region. The device further includes a gate dielectric over the second SiGe region, a gate electrode over the gate dielectric, and a source region and a drain region on opposite sides of the gate dielectric and the gate electrode.

In accordance with yet other embodiments, a method includes recessing a portion of a substrate between two insulation regions to form a recess, performing a first epitaxy to grow a first semiconductor region in the recess, and perform-

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ing a second epitaxy to grow a second semiconductor region in the recess. The first semiconductor region is relaxed. The second semiconductor region is over and contacting the first semiconductor region. The second semiconductor region has a tensile strain. A planarization is performed to level top surfaces of the second semiconductor region and the insulation regions. The insulation regions are recessed, wherein a top portion of the second semiconductor region over the insulation regions forms a semiconductor fin. The semiconductor fin is thinned to have a smaller width. A third epitaxy is performed to grow a third semiconductor region on a top surface and sidewalls of the semiconductor fin. The second semiconductor region has a conduction band lower than conduction bands of the first and the third semiconductor regions.

Although the embodiments and their advantages have been described in detail, it should be understood that various changes, substitutions and alterations can be made herein without departing from the spirit and scope of the embodiments as defined by the appended claims. Moreover, the scope of the present application is not intended to be limited to the particular embodiments of the process, machine, manufacture, and composition of matter, means, methods and steps described in the specification. As one of ordinary skill in the art will readily appreciate from the disclosure, processes, machines, manufacture, compositions of matter, means, methods, or steps, presently existing or later to be developed, that perform substantially the same function or achieve substantially the same result as the corresponding embodiments described herein may be utilized according to the disclosure. Accordingly, the appended claims are intended to include within their scope such processes, machines, manufacture, compositions of matter, means, methods, or steps. In addition, each claim constitutes a separate embodiment, and the combination of various claims and embodiments are within the scope of the disclosure.

What is claimed is:

1. A device comprising:

a substrate;
insulation regions over a portion of the substrate;
a first semiconductor region between the insulation regions and having a first conduction band;
a second semiconductor region over and adjoining the first semiconductor region, wherein the second semiconductor region comprises an upper portion higher than top surfaces of the insulation regions to form a semiconductor fin, wherein the semiconductor fin has a tensile strain and has a second conduction band lower than the first conduction band, and wherein the second semiconductor region comprises:
a wide portion; and
a narrow portion narrower than the wide portion over the wide portion, with the wide portion comprising an extension portion laterally extending beyond a respective sidewall of the narrow portion;
a third semiconductor region over and adjoining a top surface and sidewalls of the semiconductor fin, wherein the third semiconductor region has a third conduction band higher than the second conduction band; and
a gate stack overlapping both the narrow portion and the extension portion of the wide portion.

2. The device of claim 1 wherein the extension portion has a substantially flat top surface.

3. The device of claim 2, wherein the flat top surface is substantially level with or higher than top surfaces of the insulation regions.

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4. The device of claim 1, wherein the second semiconductor region has a lattice constant smaller than lattice constants of the first semiconductor region and the third semiconductor region.

5. The device of claim 1, wherein a width of the narrow portion is smaller than a width of the wide portion by a difference greater than about 2 nm.

6. The device of claim 1, wherein the third semiconductor region comprises:

a first un-doped layer substantially free from n-type impurities on the sidewalls and the top surface of the semiconductor fin; and

a doped layer over the first un-doped layer, wherein the doped layer is doped with an n-type impurity.

7. The device of claim 6, wherein the third semiconductor region further comprises a second un-doped layer overlying the doped layer, and wherein the second un-doped layer is substantially free from n-type impurities.

8. The device of claim 1 further comprising a source region and a drain region, wherein the respective sidewall of the narrow portion extends from the source region to the drain region.

9. A device comprising:

a silicon substrate;

Shallow Trench Isolation (STI) regions extending into a portion of the silicon substrate;

a first silicon germanium (SiGe) region located between and in contact with the STI regions, wherein the first SiGe region has a first germanium atomic percentage;

a silicon-containing region over the first SiGe region, wherein the silicon-containing region comprises:

a wide portion having a first sidewall and a top surface, wherein edges of the wide portion are vertically aligned to respective edges of the first SiGe region; and

a narrow portion over the wide portion and having a second sidewall, wherein the first sidewall and the second sidewall are on a same side of the silicon-containing region, and wherein the top surface of the wide portion connects the first sidewall to the second sidewall;

a second SiGe region contacting a top surface and sidewalls of the narrow portion of the silicon-containing region and a top surface of the wide portion, wherein the second SiGe region has a second germanium atomic percentage, and wherein the first and the second germanium atomic percentages are higher than a third germanium atomic percentage of the silicon-containing region;

a gate dielectric over the second SiGe region;

a gate electrode over the gate dielectric, wherein the top surface of the wide portion is overlapped by the gate electrode; and

a source region and a drain region on opposite sides of the gate dielectric and the gate electrode, wherein the second sidewall is in a plane parallel to a source-to-drain direction that connects the source region to the drain region.

10. The device of claim 9, wherein the silicon-containing region is substantially un-doped with n-type impurities, and wherein the second SiGe region comprises:

a first portion in contact with the top surface and the sidewalls of the silicon-containing region; and

a second portion over the first portion, wherein the second portion has an n-type impurity concentration higher than an n-type impurity concentration in the first portion of the second SiGe region.

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11. The device of claim 9, wherein the first SiGe region is relaxed, and wherein the silicon-containing region has a tensile stress.

12. The device of claim 9, wherein a width of the narrow portion is smaller than a width of the wide portion by a difference greater than about 2 nm.

13. The device of claim 9 further comprising a silicon cap over the second SiGe region, wherein the silicon cap is substantially free from germanium.

14. The device of claim 1, wherein the second semiconductor region further comprises a lower portion lower than the top surfaces of the insulation regions, and wherein the third semiconductor region comprises a portion over a top surface of the second semiconductor region, and sidewall portions on sidewalls of the upper portion of the second semiconductor region.

15. A device comprising:

a silicon substrate;

Shallow Trench Isolation (STI) regions extending into a portion of the silicon substrate;

a first silicon germanium (SiGe) region located between and in contact with the STI regions, wherein the first SiGe region has a first germanium atomic percentage;

a silicon-containing region over and in contact with the first SiGe region, wherein the silicon-containing region comprises:

an upper portion over top surfaces of the STI regions; and

a lower portion lower than the top surfaces of the STI region, wherein the lower portion comprises an extension portion laterally extend beyond a respective sidewall of the upper portion;

a second SiGe region contacting a top surface and sidewalls of the upper portion of the silicon-containing

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region, wherein the second SiGe region has a second germanium atomic percentage, and wherein the first and the second germanium atomic percentages are higher than a third germanium atomic percentage of the silicon-containing region;

a gate dielectric over the second SiGe region;

a gate electrode over the gate dielectric, wherein the extension portion of the lower portion of the silicon-containing region is overlapped by the gate electrode; and

a source region and a drain region on opposite sides of the gate dielectric and the gate electrode, wherein the respective sidewall of the upper portion extends from the source region to the drain region.

16. The device of claim 15, wherein the second SiGe region is un-doped with n-type impurities.

17. The device of claim 16, wherein the second SiGe region is further un-doped with p-type impurities.

18. The device of claim 15, wherein the silicon-containing region is substantially un-doped with n-type impurities, and wherein the second SiGe region comprises:

an first portion in contact with the top surface and the sidewalls of the silicon-containing region; and

a second portion over the first portion, wherein the second portion has an n-type impurity concentration higher than an n-type impurity concentration in the first portion of the second SiGe region.

19. The device of claim 1, wherein a bottom surface of the first semiconductor region is higher than a bottom surface of the insulation regions.

20. The device of claim 9, wherein a bottom surface of the first SiGe region is higher than a bottom surface of the STI regions.

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